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EFFECT OF THREE-DIMENSIONAL OBJECT TYPE AND DENSITY IN SIMULATED LOW-LEVEL FLIGHT

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Altitude control in simulated low-level flight improves significantly when three-dimensional objects are added to simulator visual scenes. However, the limited processing capacity of computer image generators (CIGs) may be used either to increase the density of objects at the expense of individual object detail and realism, or to increase the detail of objects at the expense of object density. The present investigation sought to determine whether object density or object detail is the more important factor in simulated low-level flight. Three types of three-dimensional objects were employed: (a) a control condition consisting of inverted tetrahedrons (the simplest possible three-dimensional shape); (b) highly detailed and realistic pine trees; and (c) a mixture of oak trees, pine trees, and bushes. The four levels of object density employed ranged from 3 objects per square mile to 175 objects per square mile. The task required a perceptual judgment to discriminate a change in altitude and a control action to reestablish the initial target altitude. Results indicated that object density had a greater effect on performance. Limited CIG processing capacity may, therefore, be more effectively used by increasing object density rather than individual object detail.

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SUMMARY

Pilots flying at low altitudes rely heavily on out-of-the-cockpit visual cues in order to control altitude. Unfortunately, computer-generated terrain surfaces common in many flight simulators provide very little in the way of altitude cues, thus limiting the effectiveness of simulators for training low-level flight tasks. Although two-dimensional texture provides important cues for controlling altitude in simulators, three-dimensional objects are particularly effective.

Limited computer-image generator (CIG) processing capacity places constraints on the types and densities of objects that can be used in simulator visual scenes. Specifically, individual object detail and realism can be increased only at the expense of overall object density. The purpose of the present investigation was to determine whether object detail or object density is a more important factor in simulated low-level flight. This issue was addressed with simulator scenes that contained either inverted tetrahedrons (the simplest three-dimensional shape possible) or highly detailed and realistic trees. Object density ranged from very sparse (3 objects per square mile) to very dense (175 objects per square mile). Pilots made perceptual judgments regarding change in altitude (up, down, or no change) and then performed a control action to establish a target altitude.

Results showed that object density was a more important factor than object type. Limited CIG processing capacity may, therefore, be used more effectively by increasing the density of objects in simulator scenes rather than increasing individual object detail.

PREFACE

This work was performed in support of AFHRL Work Unit No. 1123-32-03, Tactical Scene Content Requirements. One of the objectives of this work unit is to identify flight simulator visual scene content factors which contribute to training effectiveness for low-altitude flight.

The authors gratefully acknowledge the significant theoretical and methodological contributions of Dr. Philip Bruce, University of Dayton Research Institute. The authors wish to thank the instructor pilots of the 96 and 97 Flying Training Squadrons, and the 425 Tactical Fighter Training Squadron, Williams Air Force Base, Arizona, who participated as subjects in this research. The authors also wish to thank Lts Kevin Dixon and Luke Simcik who assisted in data collection. Finally, special thanks are due Ms. Marge Keslin who oversaw final editing.

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I. INTRODUCTION

Given the considerable risk and expense of training low-level flight skills in the real-world flight environment, it is desirable to use flight simulators for this training. An important characteristic of low-level flight is that pilots rely heavily on out-of-the-cockpit visual cues to estimate altitude above ground level (AGL) and to detect changes in altitude and impending contact with the ground. Unfortunately, computer-generated terrain surfaces common in many flight simulators provide very little in the way of visual cues, thus limiting the effectiveness of simulators for training low-level flight tasks.

Experienced pilots emphasize the importance of two-dimensional texture as a source of visual information for controlling altitude in low-level flight (Kellogg & Miller, 1984; Miller, 1984). Indeed, investigations of simulated low-level flight show that performance improves significantly when square texture is added to previously untextured terrain surfaces (McCormick, Smith, Lewandowski, Preskar, & Martin, 1983). Changes in speed and changes in altitude are also readily detected when grid-like texture patterns are present on simulated terrain surfaces (Owen, Warren, Jensen, & Mangold, 1981; Owen, Warren, Jensen, Mangold, & Hettinger, 1981). Despite the richness of two-dimensional texture as a source of visual cues for controlling altitude, there is considerable evidence that vertical development in the form of three-dimensional objects provides important additional cues that are not available from two-dimensional texture alone.

Buckland, Edwards, and Stephens (1981) employed a terrain-following task (target altitude of 50 feet AGL) with simulated terrains that contained only two-dimensional square texture, and with terrains that contained tree-like objects in addition to two-dimensional texture. Most performance measures favored the terrains with three-dimensional objects. When cresting the tops of hills, pilots flew significantly lower with three-dimensional objects present. Pilots also reported a preference for terrains that contained three-dimensional objects.

McCormick et al. (1983) used a variety of three-dimensional objects in combination with two-dimensional square texture. With some types of three-dimensional objects, Root Mean Square (RMS) error and maximum altitude measures were reliably better than with two-dimensional square texture alone.

Martin and Rinalducci (1983) assessed performance of a simulated low-level flight task with terrains that contained either inverted tetrahedrons (i.e., three-sided pyramids turned upside down) or two-dimensional triangular shapes resting flat on the terrain surface. Results showed that RMS deviation from a target altitude of 200 feet AGL was reliably smaller with three-dimensional objects than with two-dimensional cues. Pilots in this investigation also reported a preference for scenes containing three-dimensional objects.

Evidence from perceptual tasks also points to an advantage for three-dimensional objects. Rinalducci (1983) had subjects estimate the altitudes depicted in photographs of simulator visual scenes and found that estimates were significantly more accurate when scenes contained three-dimensional objects.

Taken together, these results provide strong evidence that three-dimensional objects are particularly useful as visual cues for altitude in simulated low-level flight. An interesting question concerns the type of three-dimensional objects to include in simulator visual scenes. Given limited computer image generator (CIG) processing capacity, the level of detail and realism of individual objects can be increased only at the expense of overall object density. Several investigations have shown that performance in simulated low-level flight tasks improves significantly when object density is increased (DeMaio & Brooks, 1982; Engle, 1980; Martin & Rinalducci, 1983; Rinalducci, 1983). Therefore, three-dimensional objects have typically been simple in shape and fairly abstract in appearance. For example, tetrahedrons composed of only four surfaces and six edges are common.

Pilots do report, however, that the apparent size of known and familiar objects (trees, buildings, vehicles, etc.) is a cue for distance and altitude in the real-world flight environment (e.g., Kellogg & Miller, 1984; Rinalducci, 1984). There is evidence from basic laboratory research to support this notion. Fitzpatrick, Pasnak, and Tyer (1982) found that the size of a familiar object (such as a playing card) affected the judged distance of the object from an observer. Unusually large objects were judged to be closer than they actually were, whereas unusually small objects were judged to be farther away. No systematic variation in judged distance was found for unfamiliar objects (i.e., geometric shapes) that varied in size. In a similar investigation, Higashiyama (1984) found that images of familiar-shaped objects of equal retinal size and distance were judged to be (a) farther than actual distance when the objects were normally large (e.g., a book) and (b) closer than actual distance when the objects were normally small (e.g., a postage stamp).

In this light, it is interesting to note that McCormick et al. (1983) employed three-dimensional objects designed to represent houses, warehouses, and trees. They reported reliable performance advantages for some types of objects compared to others. A mixture of all three types was particularly effective. Trees alone were effective to a lesser extent. From these results, it is clear that there are characteristics of objects that affect performance in simulators above and beyond the mere presence of the objects in simulator visual scenes. Since the objects themselves were little more than cube-like and cone-like shapes, it cannot be determined from these results whether the familiar appearance of objects affected performance or whether performance differences were attributable to variations in such characteristics as size and shape.

Researchers have cautioned that the precise relationship between apparent size and perceived distance is not clearly understood (Stevens, 1982). However, the implication for simulated low-level flight is that performance in simulators may improve with three-dimensional objects that

are more detailed and familiar in appearance. This issue was addressed in the present investigation with simulator scenes that contained only simple and abstract objects (i.e., inverted tetrahedrons) and with scenes that contained familiar objects such as highly detailed trees and bushes. Because familiar objects are more demanding of CIG processing capacity, an important question also concerned the possibility that performance with familiar objects would equal or exceed that obtained with abstract objects at lower levels of object density. To explore this possibility, a wide range of object densities was employed within each object type.

Performance in most investigations of simulated low-level flight has been assessed through measures of absolute altitude, either accuracy at establishing and maintaining a target altitude that is specified in feet AGL or accuracy at estimating the altitude depicted in simulator visual scenes. Pilots, however, rarely utilize absolute measures of altitude when flying at low altitudes in the real world. Some researchers have even suggested that absolute altitude is not perceived directly (Haber, 1984). More typically, pilots establish what they judge to be a safe target altitude given specific mission requirements and terrain considerations, and then detect and correct deviations relative to that altitude. In this regard, pilots often speak of "calibrating" their eyes for a specific altitude over a given terrain. This bears a resemblance to a matching-to-sample task (Ferster & Hammer, 1966).

A similar method was used in the present investigation. Subjects passively viewed a short segment of straight-and-level flight over a given terrain at a specified target altitude. They then entered a simulated cloud bank for 3 seconds, re-emerging at *one of seven* altitudes. If a deviation in altitude occurred, subjects detected and corrected that deviation relative to the initial target altitude.

II. METHOD

Subjects

Subjects were 24 male U.S. Air Force pilots who were fighter/attack/reconnaissance (FAR) rated and currently assigned as flight instructors in the T-37, T-38, or F-5 aircraft. Four subjects had tactical experience, with 2,500 to 4,500 hours of total flying time. The other subjects were first-assignment flight instructors with 350 to 1,600 hours of flying time. Subjects were randomly assigned to one of three object-type groups.

Task and Procedure

Subjects received an initial briefing on the purpose of the experiment and the layout of the simulator cockpit. To familiarize subjects with the flight characteristics of the simulator, 10 minutes of free flight were provided using a highly detailed scene modeled after a segment of real-world terrain. Following this practice, the procedure was explained and the stimulus conditions were described.

Each trial began with 20 seconds of passive straight-and-level flight at 450 knots ground speed and 150 feet altitude AGL. This period served to familiarize the subject with the out-of-the-window view at the designated target altitude of 150 feet AGL. After 20 seconds, the visual display was blanked for 3 seconds, an effect similar to flying into a fog bank. When the visual scene reappeared, the subject had full control of the aircraft, and altitude had deviated 0, 25, 50, or 75 feet upward or downward. The subject first verbally reported as quickly as possible whether his altitude had increased, decreased, or remained constant. He then immediately returned the aircraft to what he perceived as the 150-foot AGL target altitude and so signaled by depressing the gun trigger on the stick to end the trial. If the subject did not depress the trigger within 30 seconds, the trial ended automatically and the altitude at that point was recorded as his best estimate of 150 feet AGL. After each trial, subjects were verbally informed as to the correctness of their initial detection response. The subject initiated the next trial by depressing the trigger again. Figure 1 shows a graphic representation of the sequence of events described above.

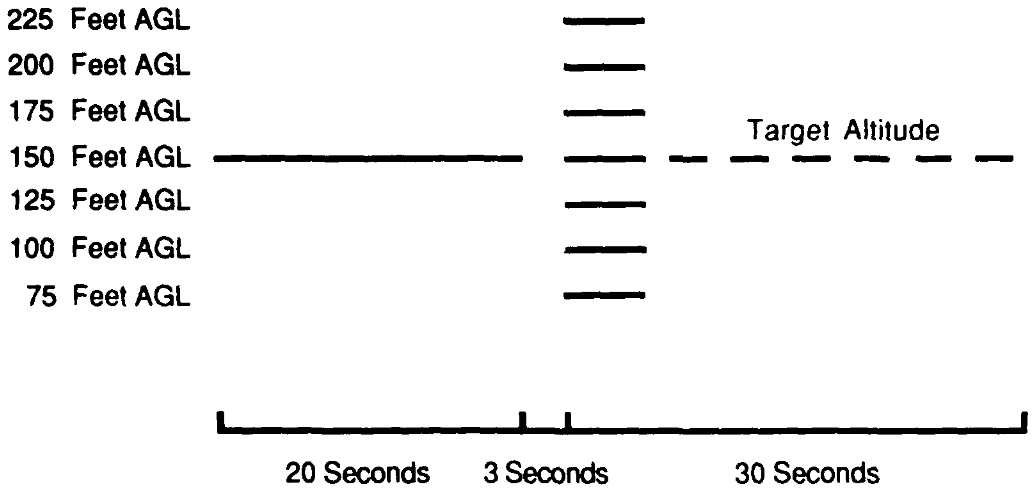


Figure 1. Temporal Sequence of Events for Each Trial.

Apparatus

A fixed-base F-16A aircraft simulator was used in conjunction with a 24-foot-diameter dome display. The image field displayed to the subject was an oval area measuring approximately 160 degrees horizontally by 60 degrees vertically. Located at the center of the image field was a high-resolution inset measuring 25 degrees horizontally by 20 degrees vertically. Resolution of the background area was approximately 8.3 arc minutes per pixel, and resolution of the inset was 1.5 arc minutes per pixel. The image field was slaved to the subject's head movements for a total field of regard of 300 degrees horizontally by 120 degrees vertically.

Real-time visual imagery was generated by the Advanced Visual Technology System (AVTS). Among its capabilities, which are similar to

those of the General Electric Compuscene IV, is cell texturing, a technique by which a complex digitized texture pattern can be stored in memory and replicated on surfaces by modulating the lightness and darkness on the surface. AVTS has an instantaneous processing capacity of 8,000 surfaces.

Experimental Design and Stimuli

The basic design was a split-plot with one between-subjects factor and two within-subjects factors. The between-subjects factor was Object Type and the within-subjects factors were Object Density and Altitude at Emergence (the altitude at which subjects emerged from the fog bank). Trials were blocked by Density level, and the order of blocks was counterbalanced by means of a Latin-square arrangement. Each level of Altitude at Emergence was repeated three times randomly within each Density block. The experimental design is outlined in Table 1.

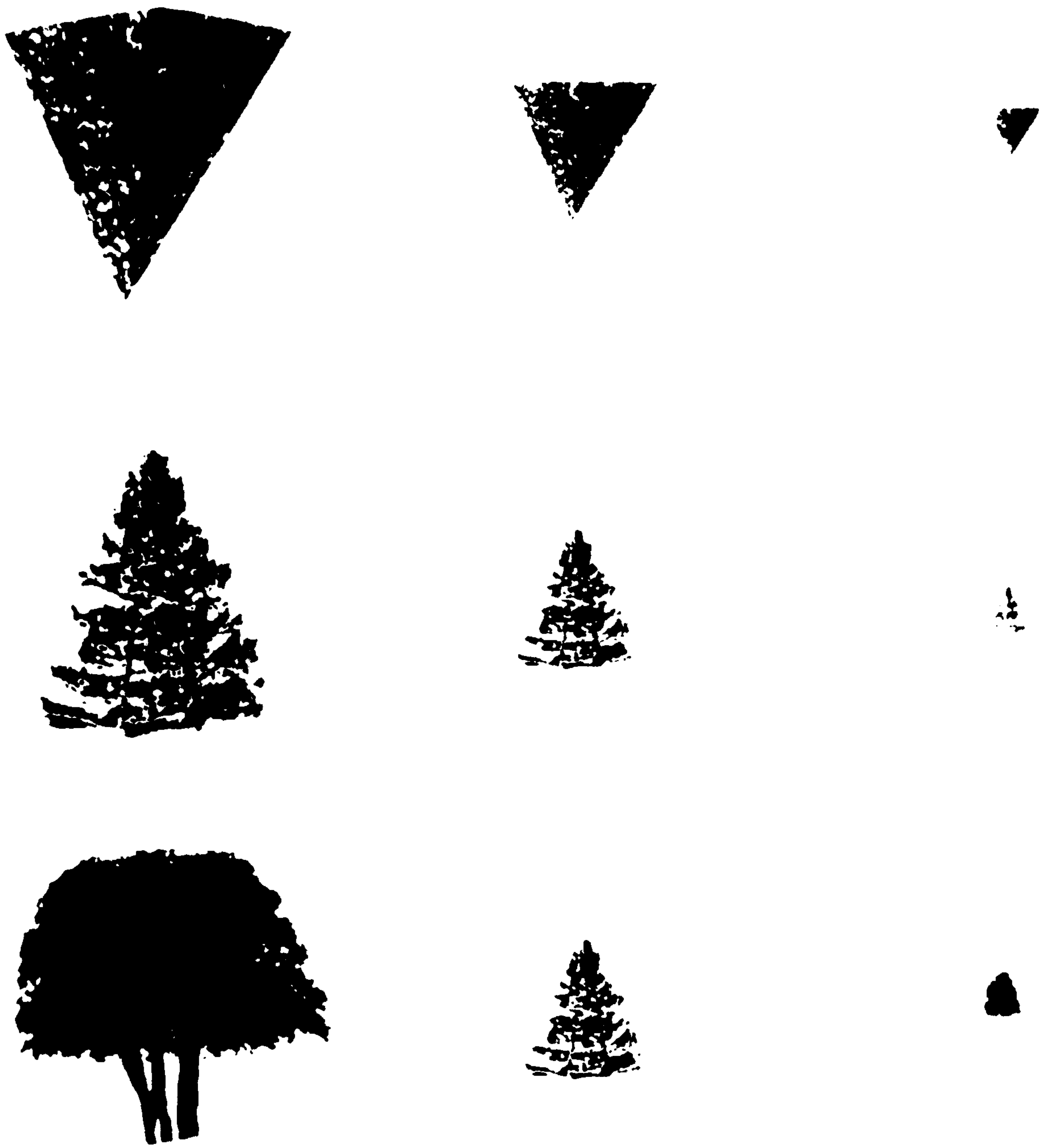
Table 1. Experimental Design

			Object density level			
Group	n	Object type	3	11	45	175
I	8	Tetrahedrons				
II	8	Pine Trees				
III	8	Mixture				

Note. Each of the seven Altitudes at Emergence was repeated three times randomly within each level of Object Density.

Three types of three-dimensional objects were employed. The first type (Tetrahedrons) was tetrahedrons that were 5, 15 or 35 feet in height and inverted such that their broad bases faced upward. Due to the presence of complex texture, a mottled-green texture pattern was added to the surface of each tetrahedron to control for possible differences between the tetrahedrons and familiar objects. The second type (Pine Trees) consisted of 5-foot, 15-foot and 35-foot cell-textured pine trees. The third type (Mixture) consisted of a mixture of cell-textured trees: 5-foot bushes, 15-foot pine trees, and 35-foot oak trees. The latter condition was employed in an attempt to replicate the finding of McCormick et al. (1983) that a mixture of objects is better than a single type of object. For each Object Type, the three sizes of objects were mixed in equal proportions and distributed randomly in simulator scenes. Photographs of objects are shown in Figure 2; luminances and contrast ratios are shown in Table 2.

There were four levels of Object Density: 175, 45, 11, and 3 objects per square mile (5,280 feet per mile). These reflect equal log intervals between 175 (the highest density possible with AVTS) and 1. Inter-object spacings were approximately 400, 800, 1,600, and 3,200 feet between objects, respectively. There were seven levels of Altitude at Emergence: 75, 100, 125, 150 (no change), 175, 200, and 225 feet AGL.



:igure 2. Photographs of Three-Dimensional Objects. The top row shows the inverted Tetrahedrons, the middle row shows the Pine Trees, and the bottom row shows the Mixture of trees. Note: Objects were photographed on a 1,000-line high-resolution monitor.

Table 2. Luminance Values and Contrast Ratios for Objects and Terrain Surfaces

	Luminance	Contrast ratio
Tetrahedrons	.095 foot-Lamberts	.651
Terrain Surface	.450 foot-Lamberts	
Pine Trees	.093 foot-Lamberts	.630
Terrain Surface	.410 foot-Lamberts	
Mixture	.077 foot-Lamberts	.675
Terrain Surface	.397 foot-Lamberts	

Note. Luminances were measured in the high-resolution inset with a Pritchard spot photometer. Contrast ratios are based on the formula: (Maximum Luminance - Minimum Luminance)/(Maximum Luminance + Minimum Luminance).

III. RESULTS

There were four response measures: The first was Detection Time, the time it took the subject to detect the direction of change in altitude after emergence from the fog bank. Either verbal response time or the time at which the subject began maneuvering the aircraft was used, whichever was shortest. The onset of maneuvering was determined by means of altitude plots. The second was Accuracy, a simple dichotomous measure indicating whether the subject was correct or incorrect in detecting the direction of change in altitude. The third measure was Final Altitude, the altitude to which the subject maneuvered the aircraft. The fourth was Maneuvering Time, the time it took the subject to maneuver to the final altitude.

A log base 10 transformation was performed on Detection Time and Maneuvering Time after adding 1.0 to each value to ensure that transformed values would be positive. Log Deviation from Target Altitude was created by subtracting 150 (the target altitude) from each Final Altitude and performing the above transformation on absolute values. Deviations above 150 feet were assigned positive values; deviations below 150 feet were assigned negative values. Accuracy scores were averaged within each treatment condition and then multiplied by 100 to form Percent Correct. Since subjects were tested three times within a given treatment condition, Percent Correct could be either 0%, 33.3%, 66.7%, or 100%. Exceptions occurred less than 3% of the time when, due to equipment malfunctions, data for only one or two trials were available for a subject in a given treatment condition.

Slightly different subsets of the data were analyzed for the four different response measures. Analyses for Log Deviation from Target

Altitude and Percent Correct were performed on the complete data set. Log Detection Time was analyzed for correct trials only. Log Maneuvering Time was analyzed for correct trials involving Altitudes at Emergence other than 150 feet, which required no maneuvering. There were missing data for Log Detection Time and Log Maneuvering Time due to the fact that some subjects had no correct responses in some treatment conditions. Due to equipment malfunctions, five treatment combinations were also tested with one less subject than initially planned. Cases with missing data were handled by means of a linear model for unbalanced data (Searle, 1987).

Results of univariate analyses of variance (ANOVAs) are shown in Tables 3 through 6 for each dependent measure. Mean performance as a function of Object Density and Altitude at Emergence is shown in Figures 3 through 6 for each dependent measure. These results may be summarized as follows: There is a consistent main effect of Altitude at Emergence. The main effect of Object Density is significant for both Log Detection Time and Percent Correct. Post hoc pairwise comparisons were performed using the Bonferoni method (.05 level of significance). Log Detection Times for 175 and 45 objects per square mile are each lower than those for 11 and 3 objects per square mile, but do not differ significantly from one another. Also, the Log Detection Time for 11 objects per square mile is lower than that for 3 objects per square mile. Mean Percent Correct is higher for 175 and 45 objects per square mile than for 3 objects per square mile. No other comparisons are significant. The two-way interaction between Object Density and Altitude at Emergence is significant for all four response measures.

The three-way interaction of Object Type by Object Density by Altitude at Emergence is statistically significant for Percent Correct; however, this is probably of little practical importance for the following reasons: First, the three-way interaction is not significant for any of the other response measures. Second, the Object Type factor is not significant by itself or in any of the two-way interactions for any measure. Third, removing the three-way interaction from the linear model has only trivial effects upon the estimated means for the two-way interaction of Object Density by Altitude at Emergence, and the main effects of Object Density and Altitude at Emergence as compared to the observed means. For example, the largest difference between observed means and estimated means with the three-way interaction removed is less than 0.5%.

Table 7 shows the means and 95% confidence intervals for each dependent measure for the Object Type factor.

IV. DISCUSSION

Object Density

An important question concerns the level of object density at which maximum cuing effectiveness is obtained. Use of too few objects yields inadequate levels of performance whereas density levels beyond which performance improvements are obtained waste valuable CIG processing

Table 3. ANOVA of Log Detection Time for Correct Responses Only

Factor	df	MS	F	(df of F)	p
O	2	0.1755	0.490	(2, 21)	.620
S	21	0.3586	--	--	--
D	3	1.1993	26.389	(3, 25)	.000
OD	6	0.0794	1.747	(6, 25)	.151
SD	25	0.0454	--	--	--
A	6	0.7654	34.030	(6, 82)	.000
OA	12	0.0107	0.474	(12, 82)	.925
SA	82	0.0225	--	--	--
DA	18	0.0492	3.650	(18, 320)	.000
ODA	36	0.0158	1.171	(36, 320)	.238
SDA	320	0.0135	--	--	--

Note. Tests are for unique effects of each factor except for O which was unadjusted for DA, ODA, and SDA. This was done because there was no unique effect for O.

Key: O = Object Type; S = Subject; D = Density; A = Altitude at Emergence.

Table 4. ANOVA of Percent Correct

Factor	df	MS	F	(df of F)	p
O	2	1351.338	1.249	(2, 20)	.308
S	20	1081.784	--	--	--
D	3	7184.402	10.291	(3, 62)	.000
OD	6	919.006	1.316	(6, 62)	.263
SD	62	698.119	--	--	--
A	6	36778.360	38.370	(6, 121)	.000
OA	12	588.456	0.614	(12, 121)	.827
SA	121	958.510	--	--	--
DA	18	1117.954	1.884	(18, 373)	.016
ODA	36	908.568	1.531	(36, 373)	.029
SDA	373	593.330	--	--	--

Note. Tests are for unique effects of each factor.

Key: O = Object Type; S = Subject; D = Density; A = Altitude at Emergence.

Table 5. ANOVA of Log Maneuvering Time for Correct Responses at Altitudes Other Than 150 Feet

Factor	df	MS	F	(df of F)	p
O	2	0.2422	0.573	(2, 21)	.572
S	21	0.4226	--	--	--
D	3	0.0535	0.979	(3, 29)	.416
OD	6	0.0359	0.658	(6, 29)	.684
SD	29	0.0546	--	--	--
A	5	0.0773	5.931	(5, 71)	.000
OA	10	0.0099	0.760	(10, 71)	.666
SA	71	0.0130	--	--	--
DA	15	0.0227	1.768	(15, 270)	.039
ODA	30	0.0182	1.416	(30, 270)	.080
SDA	270	0.0129	--	--	--

Note. Tests are for unique effects of each factor except for O which was unadjusted for DA, ODA, and SDA. The unique effect for O was not completely estimable.

Key: O = Object Type; S = Subject; D = Object Density; A = Altitude at Emergence.

Table 6. ANOVA of Log Deviation from Target Altitude

Factor	df	MS	F	(df of F)	p
O	2	7.631	1.640	(2, 20)	.219
S	20	4.653	--	--	--
D	3	2.627	1.295	(3, 62)	.284
OD	6	4.297	2.118	(6, 62)	.064
SD	62	2.028	--	--	--
A	6	16.122	13.755	(6, 121)	.000
OA	12	1.403	1.197	(12, 121)	.293
SA	121	1.172	--	--	--
DA	18	1.192	1.986	(18, 373)	.010
ODA	36	0.302	0.504	(36, 373)	.993
SDA	373	0.600	--	--	--

Note. Tests are for unique effects of each factor.

Key: O = Object Type; S = Subject; D = Object Density; A = Altitude at Emergence.

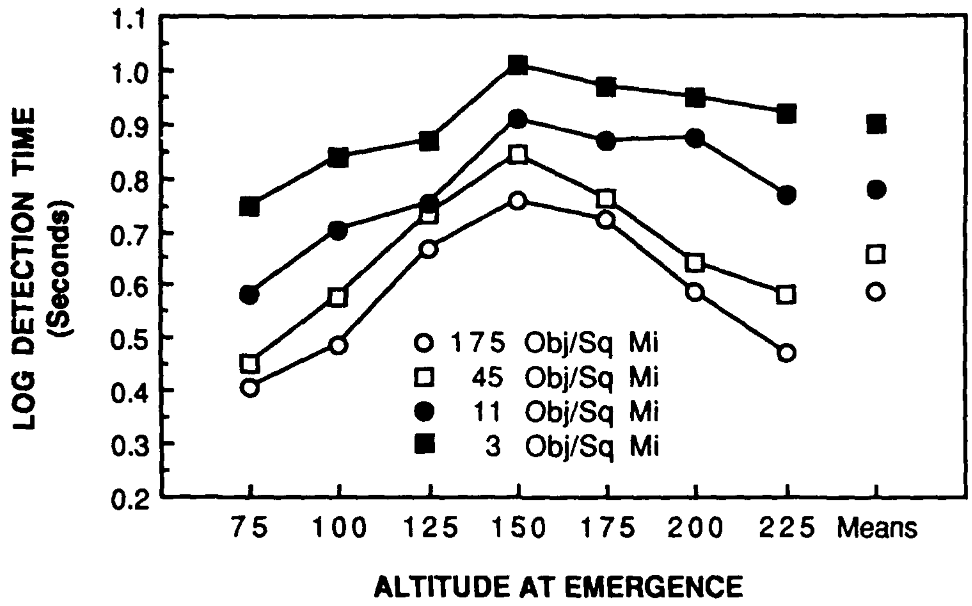


Figure 3. Log Detection Time for each Density Level as a Function of Altitude at Emergence.

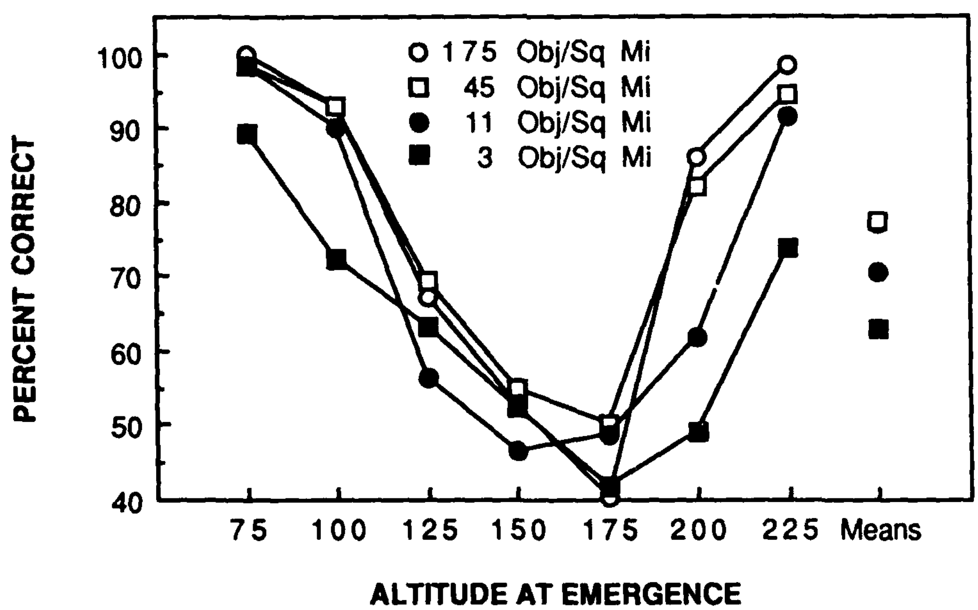


Figure 4. Percent Correct for each Density Level as a Function of Altitude at Emergence.

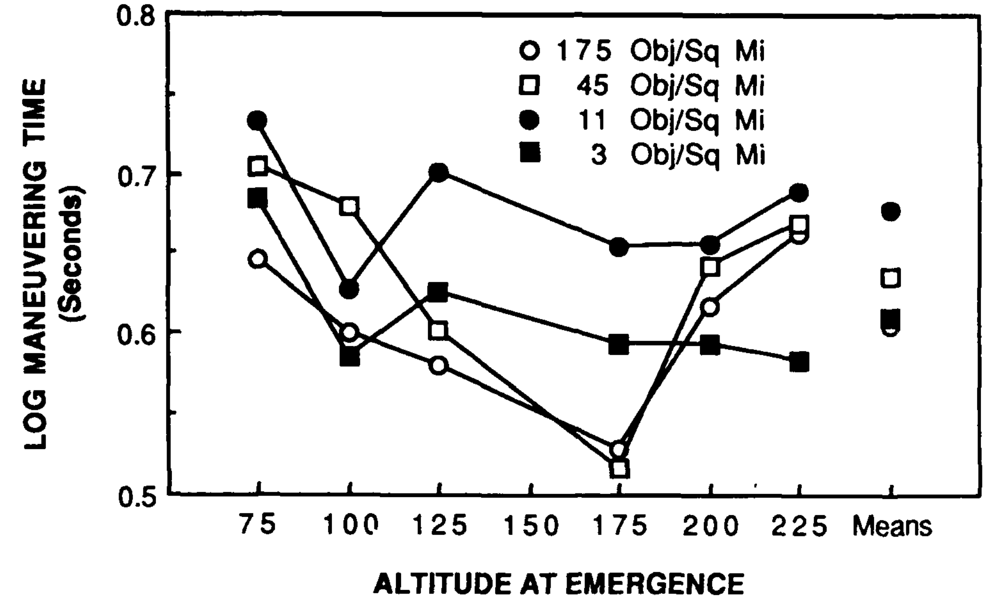


Figure 5. Log Maneuvering Time for each Density Level as a Function of Altitude at Emergence.

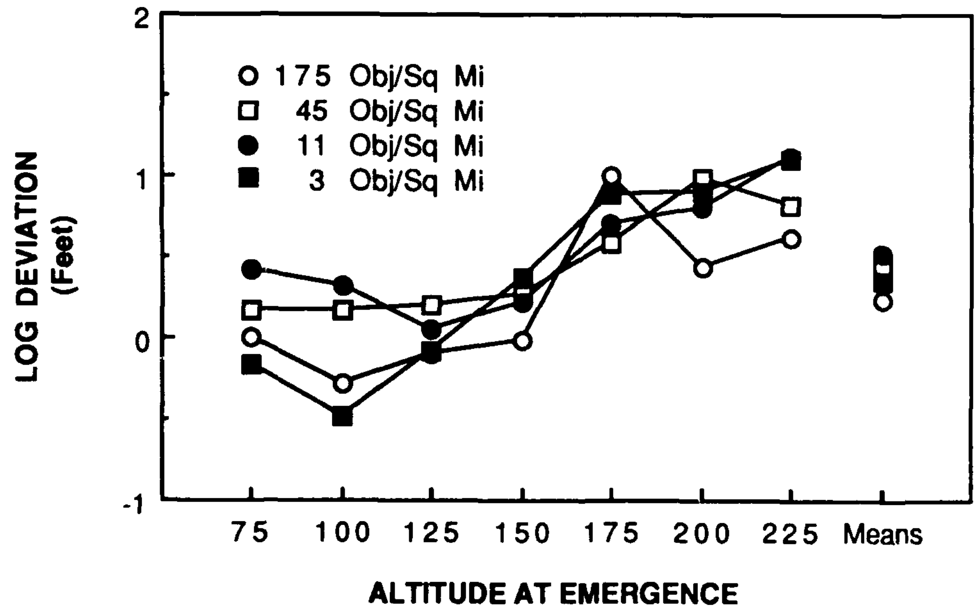


Figure 6. Log Deviation from Target Altitude for each Density Level as a Function of Altitude at Emergence.

Table 7. Means and 95% Confidence Intervals for Object Type

Object type	Log detection time	Percent correct	Log maneuvering time	Log deviation
Tetrahedrons	.756 ± .090	73.7 ± 4.6	.592 ± .105	.250 ± .301
Pine Trees	.728 ± .100	69.1 ± 4.9	.658 ± .116	.629 ± .321
Mixture	.700 ± .093	73.2 ± 4.6	.650 ± .108	.386 ± .301

capacity. Based on data compiled from several investigations of psychophysical altitude estimation, DeMaio, Rinalducci, Brooks, and Brunderman (1983) concluded that an optimal level of object density was about 12 to 15 objects per square mile (spacings of about 1,300 to 1,500 feet between objects). Log Detection Time (Figure 3) improved significantly up to a level of 45 objects per square mile (800 feet between objects), with evidence of further improvement up to the maximum of 175 objects per square mile (400 feet between objects). Percent Correct (Figure 4) improved up to a level of about 45 objects per square mile (800 feet between objects). The present results, therefore, argue that maximum cuing effectiveness may require a density as high as 175 objects per square mile, a value considerably higher than previously estimated. As previous estimates were based on psychophysical altitude estimation tasks, it is possible that procedural differences account to some extent for this discrepancy.

It is interesting that Object Density affected only Log Detection Time and Percent Correct, which are measures of perceptual sensitivity to changes in altitude. Log Maneuvering Time and Log Deviation from Final Altitude are measures of maneuvering efficiency and contain a motor component. DeMaio et al. (1983) found a strong correlation between performance on a psychophysical altitude estimation task, which was perceptual in nature, and performance on a dynamic, interactive altitude control task. They concluded that the psychophysical task was a good predictor of performance in simulators. The present finding that Object Density affected perception of change in altitude but did not affect aircraft maneuvering demonstrates that perceptual tasks do not always predict performance on dynamic, interactive tasks requiring motor control. Subjects may therefore be perceptually sensitive to simulator scene characteristics that they cannot use to control motion, a fact recently stressed by Owen, Freeman, Zaff, and Wolpert (1987). The altitude estimation task and the altitude control task of DeMaio et al. were both based on estimates of absolute altitude, and this may have constrained subjects to attend to similar types of information. Subjects in the present investigation were not constrained to focus on any particular type of information; so, the strategies employed to detect changes in altitude and those used to maneuver the aircraft may have been different. The point is that simulator visual scene content characteristics cannot be assumed to affect performance equally across a range of tasks. The question of the most appropriate task for assessing simulator visual scene content remains open.

Significant two-way interactions of Object Density by Altitude at Emergence were obtained with all four dependent measures. Detection Time and Percent Correct (Figures 3 and 4) both improved with increases in the magnitude of the change in altitude, but the improvement was larger for the higher levels of Object Density. Performance was particularly poor for the lowest level of density (3 objects per square mile) at altitudes above 150 feet AGL where subjects may have had difficulty detecting objects when very few objects were present.

For Log Maneuvering Time (Figure 5) and for Log Deviation from Target Altitude (Figure 6), the two-way interaction of Object Density by Altitude at Emergence was not readily interpretable with respect to the role of object density in simulated low-level flight. The absence of main effects indicates that Object Density was not an important factor for these two dependent measures.

Object Type

There was no evidence of a performance advantage for the detailed objects compared to the inverted tetrahedrons. Table 7 shows that although a great deal of overlap exists in the confidence intervals around various means, performance actually tended to be better with inverted tetrahedrons. The finding that performance with simple objects is as good as with detailed and realistic objects is consistent with the views of Gibson (1950), who stated that the important information for perceiving and controlling self-motion is contained in the optical flow field or optical array and need not copy the real world.

Leibowitz and Post (1982) described a possible selective degradation of visual function which may be relevant to the present discussion. They cited a study by Merritt, Newton, Sanderson, and Seltzer (1978), who assessed performance in an automobile driving simulator under a wide range of visually degraded conditions corresponding to fog, dirt particles on the windshield, etc. These factors have the primary effect of reducing overall levels of luminance and contrast. In the real-world driving environment, such conditions impair perception of road signs, hazards, etc. and typically result in high accident rates. Interestingly, subjects in the driving simulator were able to orient well on the simulated roadway despite severe visual degradation. This suggests that low levels of luminance and contrast have a greater effect on the perception of information required for stimulus identification than on the perception of information required for spatial orientation and control of self motion. The relatively low levels of display luminance and contrast in the present investigation may therefore have interfered with object identification while having little effect on perception of information required to detect a change in altitude.

A second consideration is that the range of altitudes employed in the present investigation (75 to 225 feet AGL) may not have produced detectable changes in the apparent sizes of objects. Although this range is representative of the typical low-level mission, the range of apparent sizes was actually smaller than in the Fitzpatrick et al. (1982) study, where stimulus sizes ranged between 3.41 and 9.02 degrees of visual angle. If one's eyepoint is positioned such that a 35-foot-tall object

subtends 9.02 degrees of visual angle at 75 feet AGL (a slant range of approximately 218 feet), that same object subtends 4.84 degrees of visual angle at 225 feet AGL (a slant range of 304 feet). Also, because changes in altitude were always relative to the 150-foot AGL target altitude, the functional range was even smaller. It may be that changes in the apparent size of familiar objects only become useful cues for perceiving changes in altitude when there is a broader range of apparent sizes.

V. CONCLUSIONS

The finding that Object Density was a more important factor than Object Type supports the conclusion that limited CIG processing capacity may be used more effectively by increasing the density of objects in simulator scenes rather than increasing the level of detail of individual objects. The absence of an effect of Object Type is of interest because it shows that situations exist in which no particular advantage is to be gained by enhancing the realism of simulator scenes. Increased realism should not, therefore, be implicitly embraced as a general goal in the design of flight simulators. Rather, cost effectiveness is best served by empirically identifying dimensions of scene detail and realism that affect performance and then focusing resources on those specific areas.

The present results are of particular importance to designers and users of inexpensive flight simulators, as well as part-task trainers, which lack the range of detail available with the more expensive systems. Results show that even with simulator scenes that bear little resemblance to the real-world flight environment, performance in simulators need not suffer provided task-relevant visual information is adequately represented.

REFERENCES

Buckland, G. H., Edwards, B. J., & Stephens, C. W. (1981). Flight simulator visual and instructional features for terrain flight simulation. Proceedings of the Image Generation/Display Conference II (pp. 351-362). Phoenix, AZ.

DeMaio, J., & Brooks, R. (1982). Assessment of simulator visual cueing effectiveness by psychophysical techniques. Proceedings of the Fourth Interservice/Industry Training Equipment Conference (pp. 379-381). Orlando, FL.

DeMaio, J., Rinalducci, E. J., Brooks, R., & Brunderman, J. (1983). Visual cueing effectiveness: Comparison of perception and flying performance. Proceedings of the Fifth Interservice/Industry Training Equipment Conference (pp. 92-96). Washington, DC.

Engle, R. I. (1980). Use of low altitude visual cues for flight simulation. Unpublished master's thesis, Arizona State University, Tempe, AZ.

Ferster, C. B., & Hammer, C. E., Jr. (1966). Synthesizing the components of arithmetic behavior. In Honig, W. K. (Ed.), Operant behavior: areas of research and application (pp. 634-676). New York: Appleton-Century-Crofts.

Fitzpatrick, V., Pasnak, R., & Tyer, Z. E. (1982). The effect of familiar size at familiar distances. Perception, 11, 85-91.

Gibson, J. J. (1950). Perception of the visual world. Boston: Houghton-Mifflin.

Haber, R. N. (1984). Perceptual factors in low-level flight. Proceedings of the Ninth Symposium on Psychology in the Department of Defense (pp. 489-493). Colorado Springs, CO.

Higashiyama, A. (1984). The effects of familiar size on judgments of size and distance: An interaction of viewing attitude with spatial cues. Perception & Psychophysics, 35, 305-312.

Kellogg, R. S., & Miller, M. (1984). Visual perceptual aspects of low-level, high speed flight and flight simulation. Proceedings of the Image Generation/Display Conference III (pp. 22-36). Phoenix, AZ.

Leibowitz, H. W., & Post, R. B. (1982). The two modes of processing concept and some implications. In J. Beck (Ed.), Organization and representation in perception (pp. 343-363). Hillsdale, NJ: Erlbaum.

Martin, E. L., & Rinalducci, E. J. (1983). Low-level flight simulation: Vertical cues (AFHRL-TR-83-17, AD-A133 612). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

McCormick, D., Smith, T., Lewandowski, F., Preskar, W., & Martin, E. (1983). Low-altitude database development evaluation and research (LADDER). Proceedings of the Fifth Interservice/Industry Training Equipment Conference (pp. 150-155). Washington, DC.

Merritt, J. O., Newton, R. E., Sanderson, G. A., & Seltzer, M. L. (1978). Driver visibility quality: An electro-optical meter for in-vehicle measurement of modulation transfer (MTF) (Contract DOT-HS-6-01426). Washington, DC: National Highway Safety Administration.

Miller, M. (1984). Using a limited field of view simulator to instruct high speed, low altitude flying skills. Proceedings of the Image Generation/Display Conference III (pp. 8-20). Phoenix, AZ.

Owen, D. H., Freeman, S. J., Zaff, B. F., & Wolpert, L. (1987). Perception and control of simulated self motion (AFHRL-TR-87-16, AD-A187 444). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Owen, D. H., Warren, R., Jensen, R. S., & Mangold, S. J. (1981). Optical information for detecting loss in one's own altitude. In D. H. Owens & R. S. Jensen (Eds.), Methodological approaches to identifying relevant features for visual flight simulation (Final Technical Report for AFOSR Contract No. F49620-79-C-0070, Task 1). Columbus, OH: The Ohio State University, Department of Psychology, Aviation Psychology Laboratory.

Owen, D. H., Warren, R., Jensen, R. S., Mangold, S. J., & Hettinger, L. J. (1981). Optical information for detecting loss in one's own forward speed. Acta Psycologica, 48, 203-213.

Rinalducci, E. J. (1983). Visual cues in the simulation of low level flight (AFOSR-TR-83-1016). Bolling AFB, DC: USAF Office of Scientific Research/NL.

Rinalducci, E. J. (1984). Arizona Air National Guard (AZANG) Low Altitude Terrain (LAT) Support (Contract No. F33615-81-C-0005). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Searle, S. R. (1987) Linear models for unbalanced data. New York: John Wiley & Sons.

Stevens, K. A. (1982). Computational analysis: Implications for visual simulations of terrain. In W. Richards and K. Dismukes (Eds.), Vision Research for Flight Simulation: A Report on a Workshop on Simulation of Low-Level Flight (pp. 38-64). Washington, DC: National Academy Press.

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